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PE-TR-M7314

THIRD QUARTERLY REPORT

RUBY IMPROVEMENT FOR LASERS - TASK II

DATE OF THIS REPORT: 28 FEBRUARY 1963
PERIOD COVERED: 31 OCTOBER 1962 TO 31 JANUARY 1963

U.S. Army Signal Research and Development Laboratories
U.S. Army Signal Supply Agency; Contract DA 36-039-SC-89091
DA Project No. 3A-99-21-001-05

THE PERKIN-ELMER CORPORATION
NORWALK, CONNECTICUT

PE-TR-M7314

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DA Project No. 3A-99-21-001-05

OBJECT

The objective of this contract is to evaluate and fabricate ruby material grown by the Linde Company Division of Union Carbide Corporation under Contract DA 36-039-SC-89089; and to develop improved geometries and test procedures for ruby lasers.

THE PERKIN-ELMER CORPORATION

NORWALK, CONNECTICUT

Prepared By: G. W. Dueker

SUMMARY OF STATUS

This is the Third Quarterly Report on work conducted under Contract DA-36-039-SC-89091: "Ruby Improvement for Lasers - Task II". Boule lots 4 and 5 were received, inspected, and fabricated into 1/4" x 2" rods with plane-parallel ends. The finished rods were anti-reflection coated, tested and delivered to USASRDL for further testing.

Hours Expended: During the period covered by this report, 724 man-hours were expended. Total man-hours since the beginning of the contract is 1658.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

CONFERENCES:

Persons Attending:	Fort Monmouth - Mr. M. Katzmann Mr. C. Kellington
	Perkin-Elmer - Mr. J. Atwood Mr. G. Dueker Mr. F. Zernike
Held:	January 25, 1963, Perkin-Elmer Corporation, Norwalk
Object:	To discuss the progress of the work on the contract, and plan future work.
Conclusions:	It was agreed to add measurement of line width at low temperature to the investigation. Equipment to make the measurement will be built by and remain the property of Perkin-Elmer. Only time used in making the actual measurements will be charged to the contract.

SECTION I - INTRODUCTION

1.1 PURPOSE

This Third Quarterly Report covers the period from 31 October 1962 to 31 January 1963 reporting activity occurring under Contract DA-36-039-SC-89091, for USASRDL, Fort Monmouth, New Jersey. The purpose of the investigation is to evaluate and fabricate ruby material grown by the Linde Company, Division of Union Carbide Corporation, under Contract DA-36-039-89089; to experiment with improved geometries for resonant structures, and to learn what test methods and fabrication techniques are necessary to ensure optimum performance of ruby lasers.

1.2 OUTLINE OF WORK

According to the terms of the contract, ruby and sapphire raw material is to be supplied by Fort Monmouth, for testing and fabrication by Perkin-Elmer. The optical evaluation procedure to be followed is outlined in the First and Second Quarterly Reports. In most instances, it is anticipated that maser power output, beam spread, and other important features will be measured at USASRDL. Fabrication is to be into geometries mutually agreed upon by the customer and contractor. The total number of pieces is to be 48.

Ten lots of ruby boules, comprising 33 boules in all, are to be grown under various conditions by the Linde Division. These boules are anticipated to provide a majority of the raw material to be fabricated during the investigation.

During the period covered by this report, lots three and four were received. Optical evaluation was made, and a total of 10 finished laser rods were made from them. Further evaluation of the finished pieces was made. Fluorescence line width measurement is to be added to the evaluation.

1.3 ABSTRACT

A report is given on the optical evaluation of lots three and four of ruby crystals grown by the Linde Company under Contract DA-36-039-SC-89089. The technique of fluorescence line width measurement is discussed.

SECTION II - PUBLICATIONS AND REPORTS

During the period covered by this report, no publications or other reports were issued.

SECTION III - DESCRIPTION OF NEW EQUIPMENT AND TECHNIQUES

3.1 LINE WIDTH MEASUREMENTS

The intensity of radiation passing through a medium is

$$I = I_o e^{-\alpha x}$$

where the attenuation constant α is given by*

$$\alpha = \frac{2}{\Delta\nu}\sqrt{\frac{\ln 2}{\pi}}\ \frac{\lambda_o^2}{8\pi}\ \frac{g_2}{g_1}\ \frac{(N_1 - N_2)}{\tau}$$

where

$\Delta\nu$ is the width of the spectral line in cps; λ_o is the wavelength in cm;

N_1 and N_2 are the number of atoms per c.c. in the lower and upper state;

g_1 and g_2 are the statistical weights of the lower and upper states; and

τ is the lifetime of the excited state, for spontaneous emission.

If the population of the upper state is greater than that of the lower, the absorption coefficient is negative and the medium possesses gain. The magnitude of the gain is seen to be dependent upon the spectral width of the line, which is thus an important parameter of the material.

In the case of ruby, a typical value of the line width at 77°K is about 0.3cm^{-1}** However, there is a considerable variation in this value, and experiments have indicated that strains in the crystal limit the sharpness of the line at low temperatures.

A method of measuring the line width is to use a Fabry-Perot etalon. It consists of two transparent plates; accurately spaced parallel a distance D apart, and coated on their inner surfaces with a reflective film. If monochromatic light of wavelength λ falls at an angle θ on the plates, it will be transmitted if the spacing D is such that

$$M\lambda = 2n D \cos\theta$$

where n is the index of refraction of the medium between the plates, and M is an

*Schawlow, A.L., Solid State Journal, June 1961

**Schawlow, A.L., Quantum Electronics Conference, 1961 integer. This is the condition for which the successively reflected beams are in phase, and reinforce. For other values of D, destructive interference causes the transmittance to be very low. The resolution of a Fabry-Perot is dependent on the reflectivities of the plates, and can be very high for multi-layer dielectric coatings.

In the conventional type of etalon the reflective surfaces are deposited on quartz plates which are separated by an accurately parallel spacer ring located outside the effective aperture. The material between the plates is air, and thus, to scan the wavelength of maximum transmission, the index of refraction may be changed by enclosing the etalon and changing the pressure. The index change is

$$(n_p - 1) = (n_o - 1)\ P/760$$

and is linear with pressure.

A pressure scanned Fabry-Perot is being built in this laboratory, and will be used to measure the line width of ruby supplied under the contract. Photographs of the etalon, pressure chamber, and nitrogen cryostat for cooling the ruby are shown on pages 4 and 5 (Figures 1, 2, 3, 4).

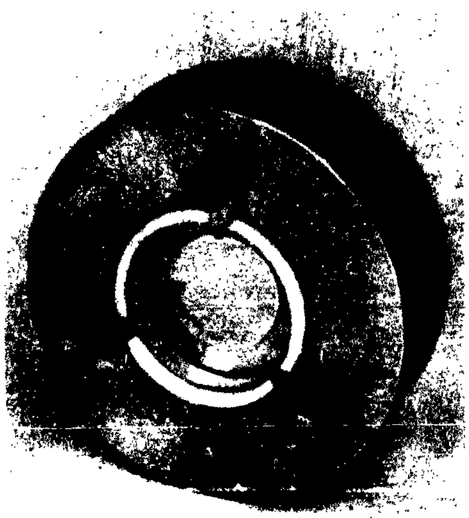

Figure 1. Etalon Plates and Mount

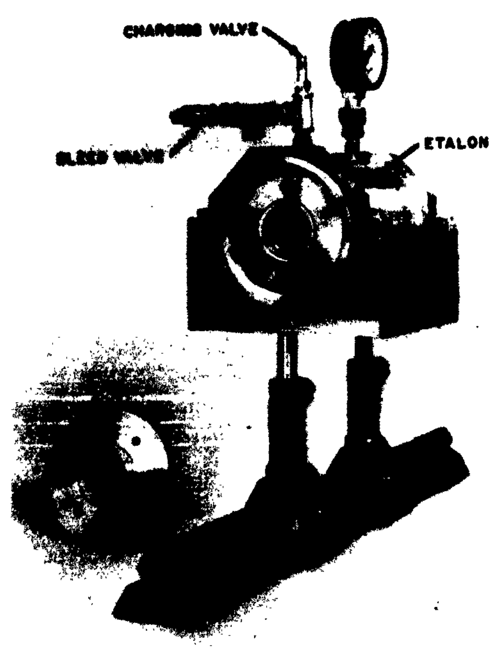

Figure 2. Pressure Chamber With End Plate Removed

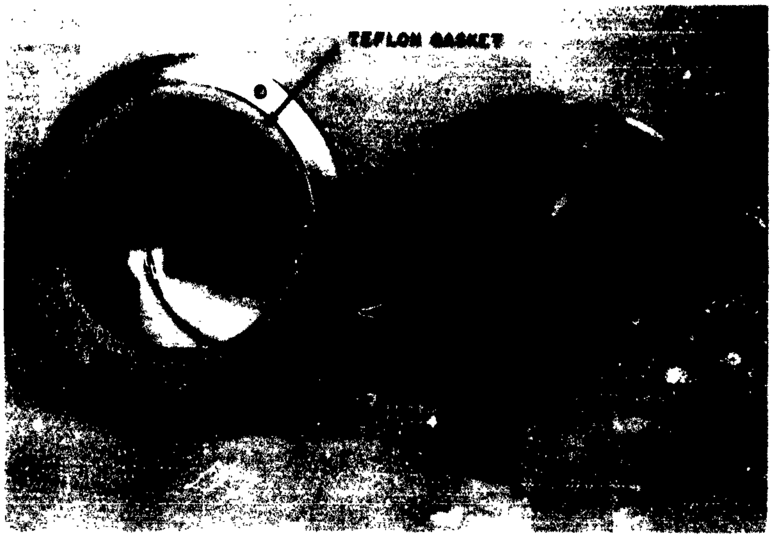

Figure 3. Disassembled Cryostat

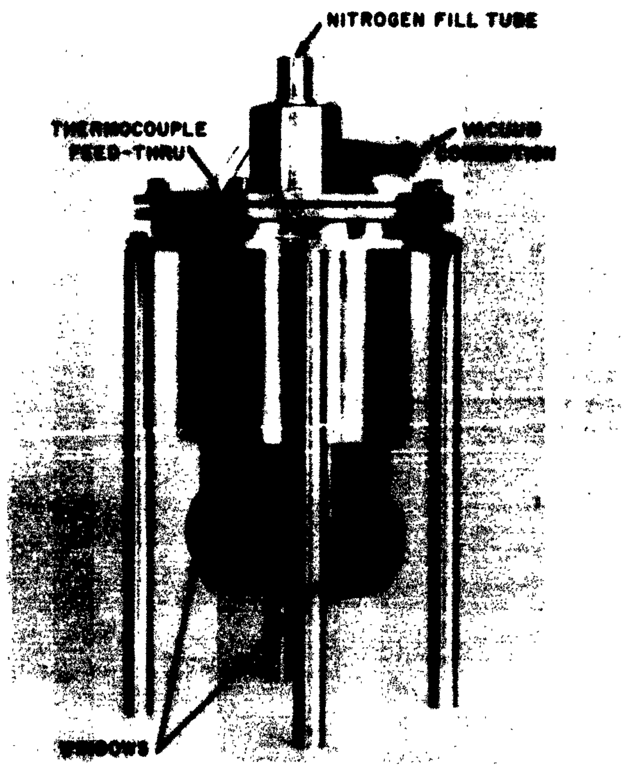

Figure 4. Assembled Cryostat

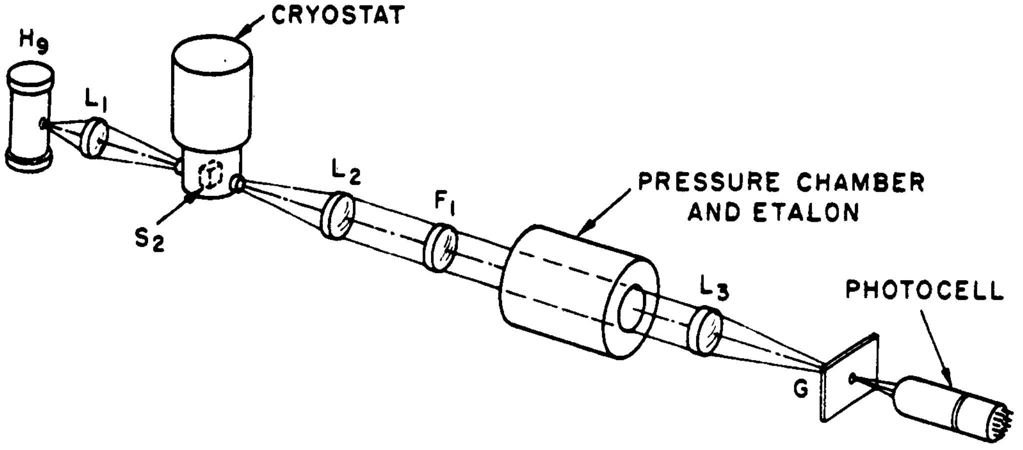

Figure 5. Schematic of Line Width Apparatus

A schematic diagram of the entire system is shown in Figure 5. The sample ruby is mounted in the cryostat to allow cooling to liquid nitrogen temperature. The excitation source, Hg, at the left, is a low pressure mercury arc. It is focussed on the sample by means of lens L_1. Fluorescence radiation from the sample is collimated by lens L_2 and passes through the etalon and pressure chamber. Filter F_1 is a dielectric multilayer spike filter centered at 6943Å, and having a bandwidth at 1/2 transmission of 100A. It serves to block the primary radiation from reaching the Fabry-Perot. The aperture at the sample is imaged at G by lens L_3, and a photocell at θ measures the transmission of the system. As the pressure in the chamber is changed, the photocell output changes as shown in Figure 6.

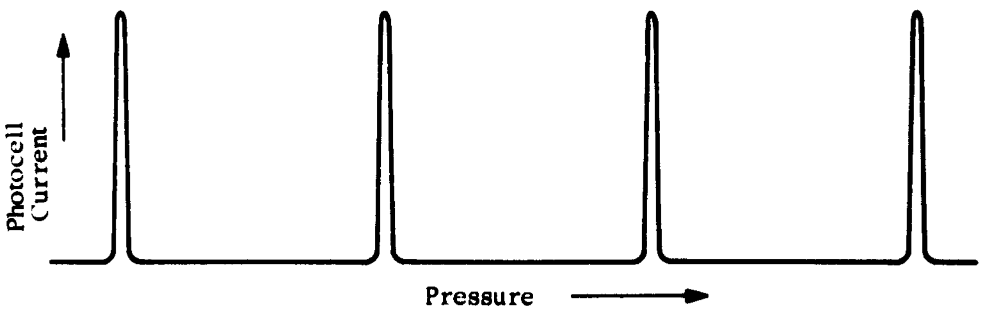

Figure 6. Photocell Output

For highly monochromatic light

$$M\lambda = 2nD\cos\theta$$

or at normal incidence where $\cos\theta = 1$

$$M = \frac{2nD}{\lambda}$$

$$|\Delta M| = \frac{2D\Delta\lambda}{\lambda^2}$$

Successive peaks represent a change of M of ±1 so that $\Delta\lambda = \frac{\lambda^2}{2D}$ or in wave numbers $\Delta\nu = \frac{1}{2D}$.

For a known plate spacing, the peak spacing is known directly in wave numbers. The width of the peaks at 1/2 height is a measure of the sharpness of the fluorescent line. If the line were perfectly monochromatic a residual width would remain which is a function of the reflectivities of the coatings, the perfection of the surfaces, and the alignment of the plates. These can be measured as a unit by illuminating the etalon with a very sharp line such as produced by a gas laser, and with this value known, the width of the ruby line may be calculated. If the line width of the particular sample is sufficiently low, the ground-state splitting of the R_1 line of .38 cm^{-1} will provide a direct calibration.*

3.2 WARPING OF BOULES WHEN CUT

Whole boule sections of lot 5 were cut slightly longer than two inches, and polished flat and parallel to less than 5 seconds of angle, to allow interferometric inspection before selecting the region to make the final 1/4 inch crystal.

After cutting the boule to prepare the final rod, each of the scrap pieces was again measured for parallel. In each case the surfaces were out of parallel by several minutes of angle, always such that the material had warped away from the cut surface. This indicates the presence of considerably compressive stress in the center of the boule.

In Figure 7 is shown a schematic diagram of the end of each boule, and the angle of the scrap pieces. The dotted circle indicates the location of the finished laser rod.

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*Schawlow, A.L., Fine-Line Spectra of Chromium Ions in Crystals, Journal of Appl. Phys., Supl. to Vol. 33, No 1, January 1963.

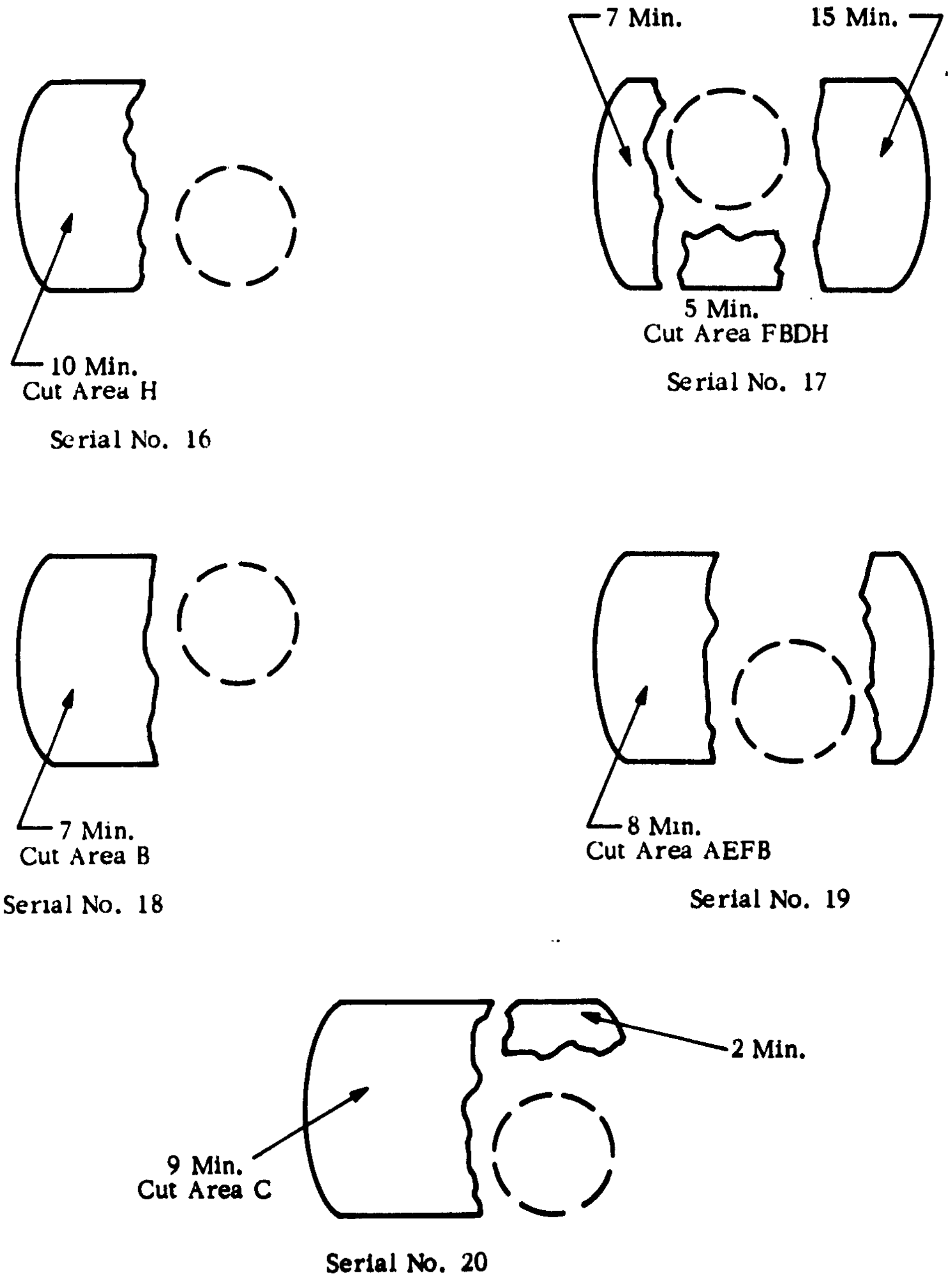


Figure 7. Boule Warping

TABLE I

Lot	Boule No.	Serial	Optical Parallel (1) .7 min/div	Ext. Parallel (2) Second	Scatter % per cm	Optical Density (1 cm) 408 mμ	Optical Density (1 cm) 553 mμ	Boule (3) Section	Comments
4	CP-134-6	11	1.3 div	2	0.08	0.62	0.60	AEGC	Layers pronounced near bottom
	CP-135-5	12	0.6	3	0.17	0.81	0.69	AC	Dark Layer up 1"; 2 veils
	CP-135-13	13	0.5	3	0.05	0.77	0.66	AC	Considerable Layering: Sharp grain boundaries
	CP-135-37	14	0.0	3	0.08	0.76	0.74	AEGC	Layer of bubbles 1/3 up: layering of Cr.
	CP-135-43	15	0.7	3	0.04	0.75	0.75	AEGC	Layering of Cr.
5	CP-136-5	16	0.2	2	0.02	0.79	0.79	H	Lineage average - layering near bottom-cut for poor fringe pattern
	CP-136-20	17	0.2	3	0.11	0.80	0.80	FBDH	Lineage good - layering low
	CP-136-24	18	0.3	2	0.11	1.02	1.02	B	Lineage high - layering average-bubbles and inclusions present
	CP-136-28	19	2.0	2	0.03	0.96	0.95	AEFB	Multiple lineage boundaries-a few bubbles
	CP-136-52	20	0.3	3	0.04	1.10	1.06	C	Bubble cluster in center-lineage high

(1) Deviation of a beam passed through crystal

(2) Measured external to crystal with autocollimator

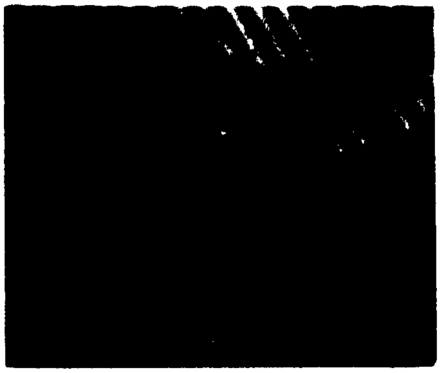
(3) See page 9, Report No. 2

Serial No. 11

Serial No. 12

Serial No. 13

Figure 8. Interferograms



Serial No. 14

Serial No. 15

Figure 8 (cont'd) Interferograms

Serial No. 16 Before Cutting

Serial No. 16 Finished

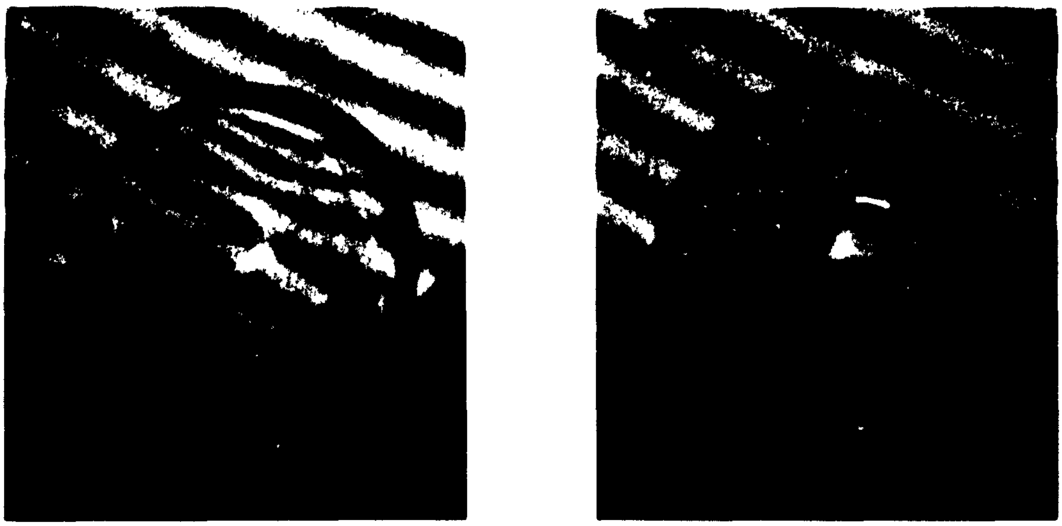
Figure 8 (cont'd) Interferograms

Serial No. 17 Before Cutting

Serial No. 17 Finished

Figure 8 (cont'd) Interferograms

Serial No. 18 Before Cutting



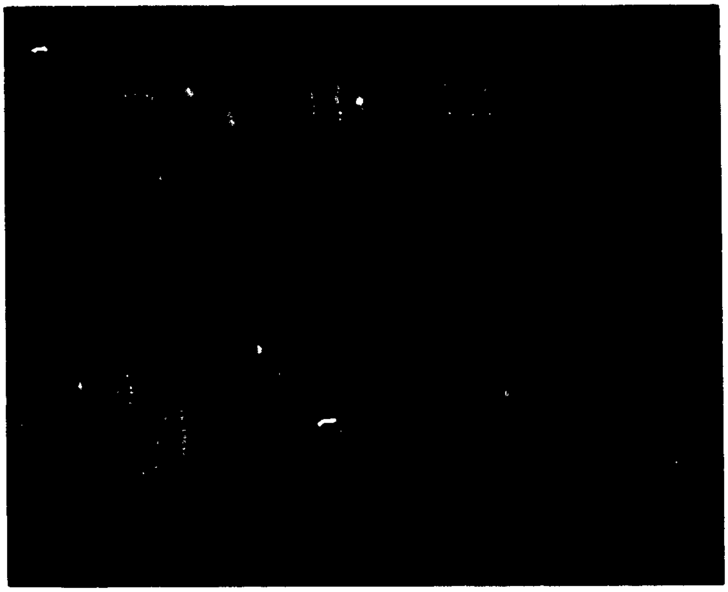
Serial No. 18 Finished

Figure 8 (cont'd) Interferograms

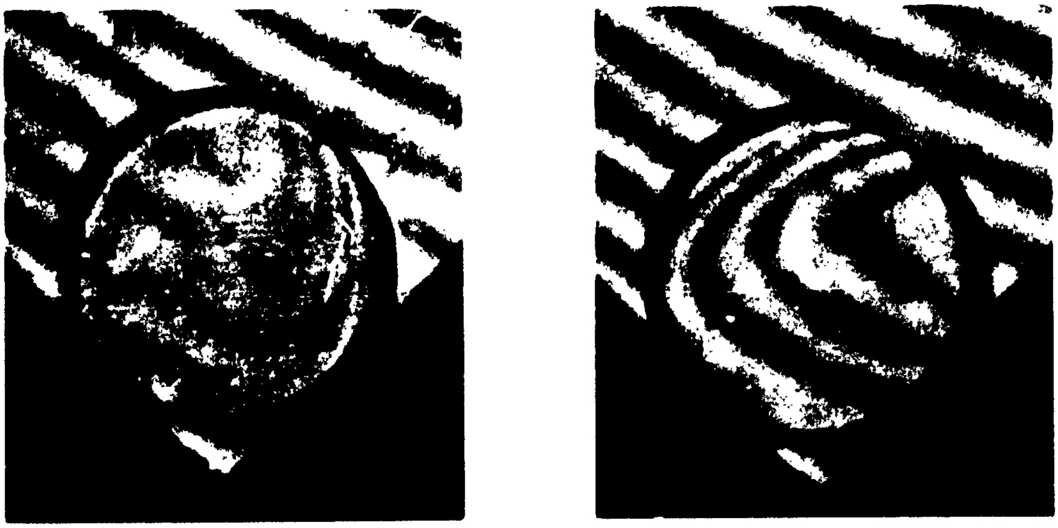
Serial No. 19 Before Cutting

Serial No. 19 Finished

Figure 8 (cont'd) Interferograms



Serial No. 20 Before Cutting



Serial No. 20 Finished

Figure 8 (cont'd) Interferograms

SECTION V - DISCUSSION OF DATA

Wide Angle Scatter: It has been suggested that the effects of scatter in a crystal laser would be to couple energy into off-axis modes of the resonator and thereby decrease the spectral purity of the output as well as increasing the threshold, and decreasing the gain. It is necessary when measuring scatter in a fluorescent crystal to distinguish between that effect, and the fluorescent radiation excited by the primary beam. For that reason, in measurements made on ruby, the primary beam is filtered with a bandpass filter centered at .9 microns, so the fluorescent line is not excited. Table I shows that crystal No. 16, cut from boule CP-136-S had the lowest scatter so far recorded, with No. 19, No. 15, and No. 20 nearly as low.

Optical Parallel: This measurement records the deviation of a parallel beam of light passed through the crystal. For a homogeneous crystal with plane parallel ends, the deviation would be zero. However, most of the crystals are not homogeneous, and internal gradient of the index causes the deviation. This effect is well correlated with the fringe pattern observed in the Twyman-Green interferometer, which also shows the gradient in the index. It may be noted that for crystal No. 19 the sharp grain boundary outlined by the fringe pattern in the interferogram is also the cause of the large beam deflection. However, the interferometer is more useful to localize the gradient, and to guide the polishing if optical correction is performed.

Strain Release: Theoretically it should be possible to calculate the relative strains in different boules by measuring the warping of the parallel faces after cutting. This measurement is being added to the data for lots 6 and subsequent lots. There is some change in the fringe pattern of the finished rod compared to the whole boule interferogram, probably due to this release of strain. Line width measurements should give a more quantitative evaluation of the effect.

Figuring: Local figuring of a rod to correct for internal index gradient was postponed until the next period, to allow for a wider choice of crystals.

SECTION VI - CONCLUSIONS

A quantitative evaluation of the residual stress in ruby is required, both as a check on the effectiveness of various growth techniques and because of its effect on line width and threshold in maser action. This measurement can best be made using a pressure scanned Fabry-Perot interferometer.

The optical parallel measurement substantially duplicates the information obtained from the interferograms. The interferograms have the advantage of providing precise location of the index gradients in the crystal.

Wide-angle scatter for the various finished crystals shows significant difference among them. The higher value for No. 14 is probably caused by the layer of bubbles, which could not be avoided in locating a two-inch rod.

SECTION VII - SUMMARY OF WORK PERFORMED THIS QUARTER

Optical evaluation and fabrication of finished laser crystals was completed for lots 4 and 5 of ruby boules supplied by the Linde Division. The finished crystals were delivered to Fort Monmouth. Processing was begun on lots 6 and 7, delivered during the quarter.

SECTION VIII - PROGRAM FOR NEXT QUARTER

The remaining lots called for under the contract will be received and processed. Measurement of fluorescent line width will be added to the data already being provided. This data will also be provided from scrap sections remaining from boules previously delivered.

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G. W. Dueker
Report No. M7314, 28 Feb. 63, 22 pp 8 illus.
Prime Contract DA36-039-SC-89091

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2. Contract DA36-039-SC-89091

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